Faculty of Manufacturing Engineering

EFFECT OF INJECTION MOULDING PARAMETERS ON WARPAGE DEFLECTION

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DECLARATION

I declare that this thesis entitled “Effect of Injection Moulding Parameters on Warpage Deflection” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : .....

Date : .....

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature :…….....

Supervisor Name :…….....

Date :…….....

DEDICATION

To my beloved family

ABSTRACT

Injection moulding is a process that can be characterised as their ability to produce high production rates with accurately product size and complex part shape. Generally, there are four elements affected the quality of injection moulded parts such as machine parameters, mould design, plastic materials and operator. In order to ensure quality of injection moulding parts can be produced at minimum cost and maximum productivity, the appropriate machine setting parameters are the priority should be achieved. Variation of process parameters are unavoidable in production of injection moulding and affected the quality of part because involved enormous process parameters. The purpose of this study is to analyze the effect of injection moulding parameters that are including cavity temperature, core temperature, mould temperature, melt temperature and cooling time. The main response of this study is to investigate the warpage deflection using simulation software and actual experimental method. The experiment was performed using injection moulding machine Arburg 420C 800-250 while simulation was done using Moldflow^{TM} Plastic Insight (MPI) software. Design of experiment (DOE) using Taguchi method was applied to design the experimental runs and it was used to analyze the significant factors that affected the warpage deflection. Three methods of investigation work were performed in this research. First investigation work was performed by compared the deviation percentage between simulation Moldflow^{TM} software and actual experimental method using different core and cavity mould temperature gradient. Second and third investigation works focus on optimized parameters using whole cold mould and whole hot mould where both investigation works were performed using simulation Moldflow^{TM} software. Analysis of variance (ANOVA) was used as statistical tools to get the percentage of contribution for each factor and to find the interaction between parameters involved. The average deviation percentage of warpage deflection by simulation software and actual experiment for first investigation work using different mould core and cavity temperature gradient was found 12.80%. The improvement of warpage deflection between those three investigation works shows that the warpage deflection is improved at 89.53% from 0.5716mm to 0.0599mm between first and third investigation work. Meanwhile, warpage reduction between first and second investigation is 83.52% and between second and third investigation is 35.31%. Result shows that the lower differences between core and cavity temperature contributes smaller warpage deflection. On the other hand hot mould temperature controlled contributes less warpage deflection as compared to cold mould. This study proved that with appropriate control parameters in injection moulding process can produce better plastic products quality.

ABSTRAK

Pengacuan suntikan adalah satu proses yang dapat disifatkan mempunyai kemampuan untuk menghasilkan sesuatu produk dengan kadar pengeluaran yang tinggi, saiz produk yang tepat dan bentuk produk yang kompleks. Secara umumnya, terdapat empat elemen yang memberikan kesan ke atas kualiti pengacuan suntikan sesuatu produk seperti parameter mesin, reka bentuk acuan, bahan plastik dan operator. Bagi memastikan kualiti produk acuan suntikan boleh dihasilkan pada kos yang minimum dan produktiviti yang maksimum, tetapan parameter mesin yang sesuai adalah perkara pertama yang perlu dicapai. Variasi proses parameter tidak dapat dielakkan dalam pengeluaran acuan suntikan dan ianya memberi kesan kepada kualiti sesuatu produk kerana melibatkan proses parameter yang sangat banyak. Tujuan kajian ini adalah untuk menganalisa kesan parameter pengacuan suntikan seperti suhu rongga, suhu teras, suhu acuan, suhu leburan dan masa penyejukan. Respon utama kajian ini adalah untuk menyiasat kesan ledingan dengan menggunakan kaedah simulasi dan eksperimen. Eksperimen ini dijalankan dengan menggunakan mesin acuan suntikan Arburg 420C 800-250 manakala simulasi dilakukan dengan menggunakan perisian Moldflow^{TM} Plastic Insight (MPI). Rekabentuk eksperimen (DOE) menggunakan kaedah Taguchi telah digunakan untuk merancang eksperimen dan ianya digunakan untuk menganalisa faktor-faktor penting yang mempengaruhi ledingan. Tiga kaedah penyelidikan telah dijalankan dalam kajian ini. Kaedah penyelidikan pertama ialah melalui perbandingan peratusan sisihan antara perisian Moldflow^{TM} simulasi dan kaedah eksperimen sebenar dengan menggunakan suhu acuan teras dan rongga yang berbeza. Kerja penyelidikan kedua dan ketiga memberi penekanan kepada mengoptimumkan parameter menggunakan simulasi perisian Moldflow^{TM}. Analisa varians (ANOVA) digunakan sebagai alat statistik untuk mendapatkan peratusan sumbangan bagi setiap faktor dan mengenalpasti interaksi di antara parameter yang terlibat. Purata peratusan sisihan ledingan di antara perisian simulasi dan eksperimen sebenar untuk kaedah penyelidikan pertama bagi suhu acuan teras dan rongga berbeza adalah sebanyak 12.80%. Penambahbaikan nilai ledingan di antara ketiga-tiga kaedah penyelidikan menunjukkan bahawa ledingan bertambah baik sebanyak 89.53% dari 0.5716mm kepada 0.0599mm antara kaedah penyelidikan pertama dan ketiga. Sementara itu, pengurangan ledingan antara kaedah penyelidikan pertama dan kedua adalah 83.52% dan antara kaedah penyelidikan kedua dan ketiga adalah 35.31%. Keputusan menunjukkan bahawa perbezaan yang lebih rendah di antara suhu teras dan suhu rongga menyumbang ledingan yang lebih kecil dan acuan suhu panas menyumbang kurang ledingan berbanding acuan sejuk. Oleh itu, ia membuktikan bahawa dengan pengawalan parameter yang sesuai dalam proses suntikan plastik boleh menghasilkan produk plastik yang lebih berkualiti.

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DOE	-	Design of experiment
ANOVA	-	Analysis of variance
MPI	-	Moldflow^{TM} plastic insight
OA	-	Orthogonal array
CAE	-	Computer aided engineering
PP	-	Polypropylene
US	-	United State
RSM	-	Response surface method
S/N	-	Signal to noise
SS	-	Sum of square
DF	-	Degree of freedom
MS	-	Mean square
s	-	Second
mm	-	Millimeter
ºC	-	Degree celcius

LIST OF PUBLICATIONS

Mohd Amran, Siti Salmah, Mohd Zaki, Raja Izamshah, Mohd Hadzley, Sivarao Subramonian, Mohd Shahir, Mohd Amri, 2014. The Effect of Pressure on Warpage of Dumbbell Plastic Part in Injection Moulding Machine. Advanced Materials Research, Vol. 903 (2014), pp. 61-66.

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CHAPTER 1

INTRODUCTION

This chapter describes the background of the project research, problem statement, scope of study, objectives and the overall organization of the contents in this thesis.

1.1 Background

Plastic industry is one of the fastest growing major industries in the world. Usage of plastic materials increases from time to time. Life without plastics is rather hard to imagine. Every day, human rely on plastic items such as household, automotive parts, medical devices and others. Department of Skills Development Ministry of Human Resources (2013) reported that Malaysia produces more than 60% of the products is manufactured from plastic materials.

There are varieties of processing method that can be used to convert the plastic raw materials into end product. Common plastic processes involved are extrusion, injection moulding, blow moulding, compression moulding, transfer moulding and rotational moulding.

However, injection moulding is one of the most important polymer processing operations in plastic industry. Zhou (2013) reported that among, all plastic products about one third are produced by injection moulding process. Meanwhile, Kittisorn (2004) stated that injection moulding accounts around 47% of all plastic products manufactured. This is

because of injection moulding process having many advantages such as can produce complex shape of plastic parts, ability to produce good dimensional ability, mass production, short cycle operation time etc. Subsequently, injection moulding is widely used for manufacturing a variety of plastic parts, from the smallest component to entire body panels of cars (Wolf, 2012).

Four elements that affected the quality of injection moulded parts are machine setting parameters, mould conditions, type of plastic materials and human error during handling the injection moulding operations. Further, contributions of each element approximately are type of plastic materials 10%, human error 10%, mould conditions 20% and machine setting parameters 60% (Kamal et al., 2009). Nevertheless, it is difficult to control injection machine setting parameters due to many parameters involved in injection moulding process. Thus, several approaches have been applied in injection moulding to study about the process parameters such as using trial and error method, simulation using software and optimizing process parameter by design of experiment (DOE). Trial and error method has insufficiently to support the plastic polymer product development due to increasing demand for high quality product and short production time (Fuh et al., 2004). Simulation of polymer processing is getting more applicable in industry because it helps to forecast the problems that may occur, study of process parameters control and optimized processing conditions. In addition, DOE approached enables to gaining an in-depth knowledge of the process interaction. Therefore, simulation method and DOE approached are more preferred in injection moulding due to their capability to lead toward fast, cost effective and reliability.

Although, injection moulding is an important process for plastic production, possibility getting various defects can be found due to complex processing involved.

Defects such as warpage, short shot, flashing, burn marks, sink marks, shrinkage, and weld line are the common problems that impact product quality in injection moulding process.

Warpage defect becomes a common pitfall in injection moulding process especially for thin plastic parts. Warpage can be defined as dimensional distortion from the intended shape of the plastic part in a moulded product after it was ejected from the mould in injection moulding process (Fischer, 2012). It causes a part to bend or twist out of shape and alters dimensions as well as the contours and angles of the part (Alfreda, 2006). Consequently, the warpage part can cause failure to surface quality and poor part assembly. Therefore, the ability to reduce the amount of warpage in plastic is very useful in all stages of the product life cycle. Knowing how process setting parameters contribute to warpage phenomenon and minimize them becomes increasingly important. Therefore, this research studies the effect of injection moulding parameters on the warpage of dumbbell product. The simulation method using Moldflow^{TM} software and experimental operation are performed through input various process parameters; melt temperature, mould temperature, cooling time, core and cavity temperature. Then, warpage deflection is investigated as output response. Mould temperature was controlled using water for cold mould and oil for hot mould. Then, Taguchi method and analysis of variance (ANOVA) were performed as statistical tools.

1.2 Problem Statement

Nowadays, electronic product such as handphone, remote control, digital watch, laptop, note book, camera, video cam, television etc. are design to become lighter, thinner and smaller to fulfil market demand. Figure 1.1 shows the example of product development for television from era 1930 to 2010 century. It is obviously shown that the development of the television becomes lighter and thinner. One way to ensure lighter and thinner plastic part produce is by reduces the wall thickness. However, producing a lighter, thinner and smaller part was the challenges to the plastic industry because it can produce higher of warpage deflection (Huang and Tai 2001). Ranran and Huimin (2013) investigate the defect of warpage on the washing machine control panel using moldflow software and found that mould having unbalanced gate location produce higher warpage deflection. Wang et al., (2012) reveal that automobile dashboard having higher warpage due to the limitation of the gating system. Furthermore, Sun et al., (2011) found that warpage deformation was minimized after analyse using orthogonal experiment designation.

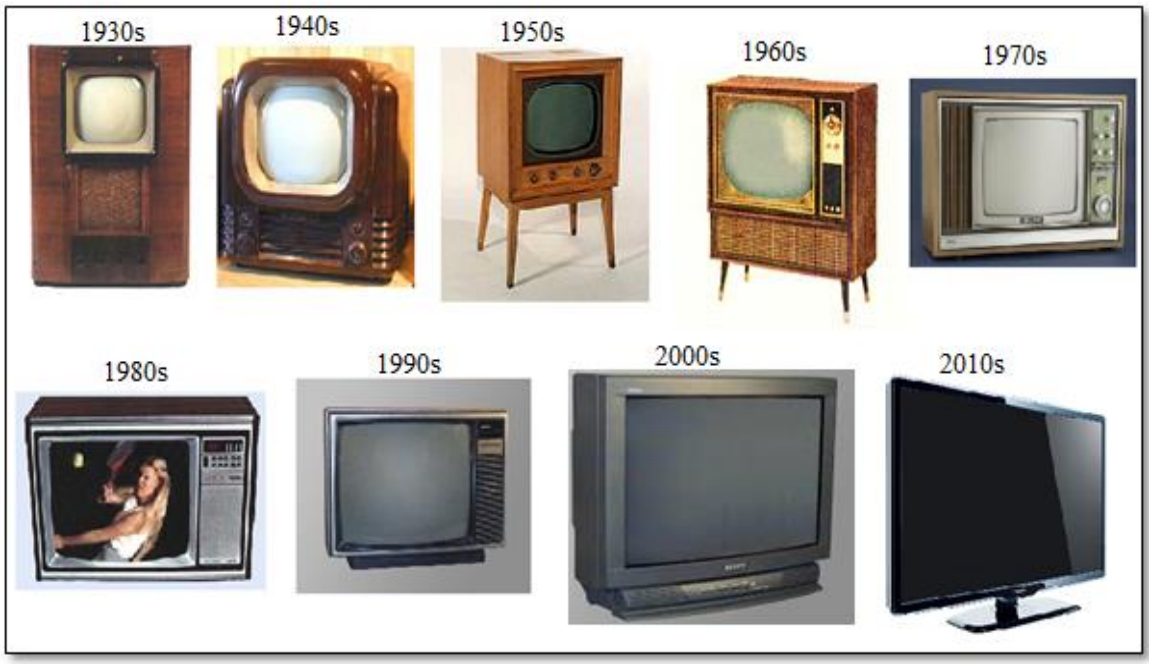

Figure 1.1: Development of Television Commercialization (Lia, 2013)

As well know that, warpage defect is one of the big issues in injection moulding process (Subramanian, 2011). This defect will impact the final of the product and will cause the product to be rejected. Therefore, it's become motivation to many researchers to find the best combination of plastic materials, optimum process setting parameters and prediction using simulation study. Simulation method become essential due to many parameters involved in injection moulding process.

In injection moulding process, plastic material is heated until molten, injected into the mould, cooled rapidly and then ejected from the mould. Normally, the mould temperature is lower than hot melt plastic temperature during injected. Consequences, the skin touching of hot melt plastic and mould surface lead the temperature of the mould wall instantaneously causing enormous temperature change between them. The exchange of heat adding with as well as thickness and pressure variations throughout the structure, cause the component to have a non-uniform shrinkage rate. The non-uniform shrinkage is one from the most contribution causes of warpage which involved many process parameters. Hence, knowing the process parameters that contribute to warpage defect becomes increasingly important. In order to minimize the formation of warpage defect, studies about how process parameters affect on the warpage is very significant. Then, this research focuses on the effect of melt temperature, mould temperature, cooling time, core and cavity temperature on warpage deflection based on past researcher summarization and importance of those parameters selected towards warpage deflection as discussed in literature review.

1.3 Objectives

The main objective of this research is to study the effect of injection moulding parameters on warpage deflection. To achieve main objective, three sub objectives are outline as follows:

1. To investigate the effect of injection moulding parameters such as melt temperature, mould temperature, cooling time, core and cavity temperature on warpage deflection.
2. To identify the percentage of deviation warpage deflection between simulation software and actual experiment.
3. To determine the smallest warpage deflection between three investigation works that are different core and cavity mould temperature gradient, whole cold mould and whole hot mould.

1.4 Scope

This project focuses on study the effect of injection moulding process parameters on warpage deflection. Injection moulding machine Arburg 420C 800-250 was used as main equipment in this research. It is due to availability of this machine in Polymer Laboratory, Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM). Injection moulding parameters that investigated were melt temperature, mould temperature, cooling time, core and cavity temperature. The mould used in this research was two-plate dumbbell injection mould. Horizontal optical comparator was used as measurement equipment the warpage deflection. There were three investigation work of research study. The first investigation work was performed using different mould temperature gradient between cold at mould core side and hot at mould cavity side using simulation software and experiment operation approach. The second investigation work